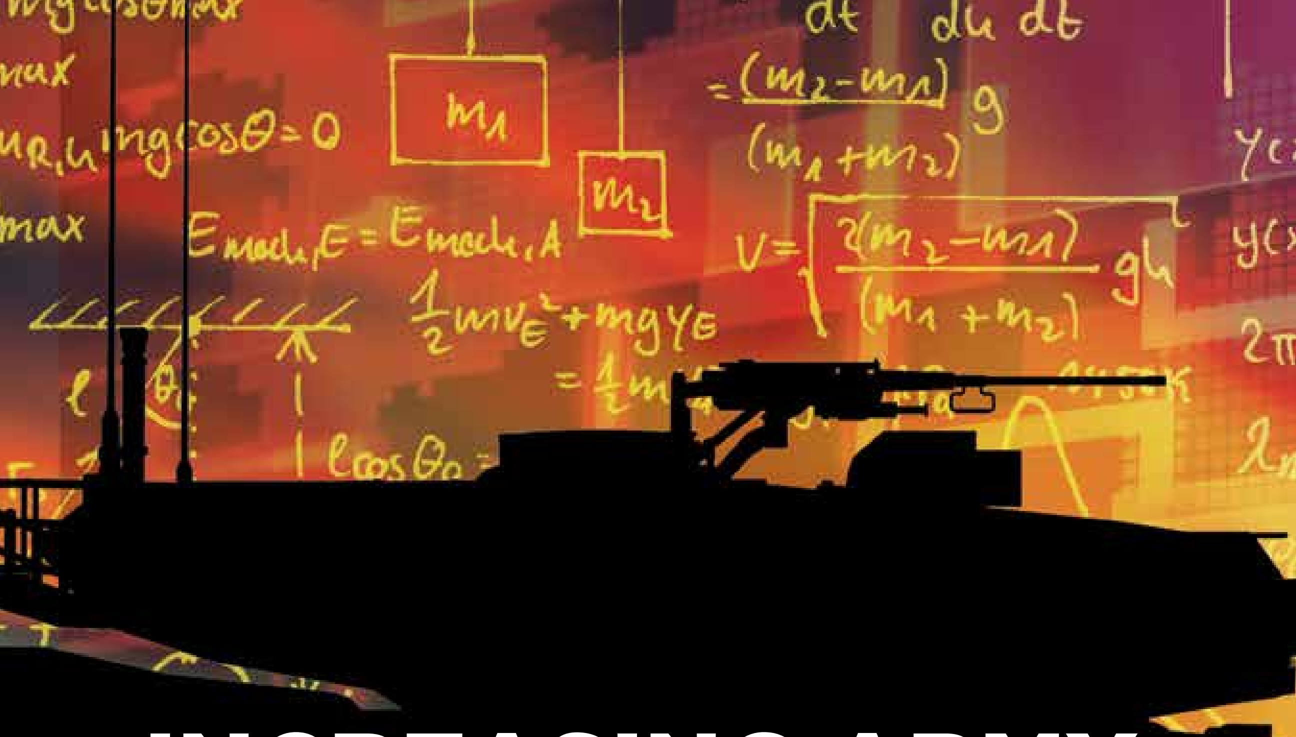

INCREASING ARMY SUPPLY CHAIN PERFORMANCE Using an Integrated End-to-End METRICS SYSTEM

Fan T. Tseng, Laird Burns, James T. Simpson, and David Berkowitz

Army Materiel Command and the University of Alabama in Huntsville partnered to develop an integrated end-to-end performance metrics system. The integration includes data pulls from multiple data systems into a metrics calculation and aggregation system that generates strategic performance metrics such as Customer Wait Time (CWT), with capabilities spanning from bottom-up supply chain performance aggregation capabilities to in-depth traceability to source (tactical) level data and documents. To support the best national defense, we must ensure that our warfighters receive the supply support they need in a timely and efficient manner. Supporting this

effort requires a near-real-time system that measures and reports on supply chain strategic performance characteristics such as CWT. Data integrity is an integral part of the process, as is reaching common agreement on appropriate data sources, algorithms to calculate metrics, and the design of a visual dashboard that supports leadership decisions and performance evaluation, with drill-down capability for lower level decision making.

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Image designed by Diane Fleischer

The current environment for the DoD is one of changing demands: recent high demand for parts needed during engagement in theater has been replaced with inventory rationalization due to drawdowns, new budgetary pressures to reduce costs and expenditures, and a call to emulate commercial practices of efficient supply chain management. In order to achieve greater management visibility across their supply chains, Army Materiel Command (AMC), headquartered in Huntsville, Alabama, partnered with University of Alabama–Huntsville (UAH) in a multiyear project to develop a supply chain performance metrics framework that provides a more comprehensive and integrated end-to-end supply chain metrics system. This research project, named the Enterprise Supply Chain Analysis & Logistics Engine (eSCALE) project, was managed by AMC for the purpose of expanding its scope to all AMC commands.

A principal objective of the project was to create a metrics framework and a prototype analytical calculation and aggregation engine to drive a near-real-time tool (Dashboard) for integrated, supply chain performance visualization, with supportive data reporting. The development of an operational metrics system embedded in a software program was specifically not part of the task. However, the development of a performance measurement framework that demonstrates "thought leadership" and advances in supply chain performance metrics necessitated that we create a prototype system to demonstrate the integration and comprehensive features of such a metrics framework. This project was to look beyond and add to the metrics framework already adopted by DoD.

DoD has previously adopted the supply chain operations reference (SCOR) model (Supply Chain Council, 2016), but AMC wanted a fresh and independent assessment of a metrics framework to aid in redefining existing metrics, provide increased visibility, and enable proactive action in both supply chain and acquisition processes. Our team was free to use guidelines from SCOR and other metrics frameworks, but we were not limited to those or necessarily required to incorporate those views in this research project. The research team was focused on developing a new approach to integrated

supply chain metrics. In particular, we were specifically informed that our task was "thought leadership" on the subject, and not to write executable code for direct implementation.

As the three-phase project progressed, it focused on three dimensions for metrics: *on-time performance, efficiency, and quality*. On-time performance measures whether soldiers in the field received items ordered within a standard lead time for the item. Efficiency focuses on the total cost to the Army for providing the item. Quality focuses on initial quality and fielded life—or reliability—of the item, as well as related quality costs, according to standards for initial quality and field reliability.

The first phase of the project involved identifying and defining metrics that measure supply chain performance of the entire Class IX Army supply chain. Class IX items are repair parts and components for all maintainable equipment, ranging from small parts to complex engines and transmissions for tanks and aircraft. The second phase of the project integrated the metrics into a web-based visualization tool—the "Dashboard." In the third phase, the project sought to develop a framework of a broad-based metrics system to

- measure and evaluate supply chain effectiveness;
- communicate metrics performance standards;
- direct attention to performance areas requiring management intervention;
- identify the root causes of existing or potential performance throughout the supply chain; and to
- more effectively manage total ownership cost.

Project success criteria were not spelled out in a formal requirements document. The sponsoring lieutenant general was seeking not a specific prescribed outcome but a fresh look at devising a metrics framework of highly integrated and near-real-time metrics. With such a framework, senior leadership could effectively assess areas of strong supply chain performance and areas that need attention to improve results. A dashboard

and drill-down capability were seen as desirable characteristics of such a system, but how to derive the functionality and what it would look like were left to the collaborative work between the research team and Army personnel supporting the project.

Measurement Challenges

Measurement systems should be evaluated as a closed-loop control scheme, where multi-organizational-level and multi-echelon metrics constitute an integrated system with performance specifications and feedback loops for ongoing and dynamic performance measurement (Bititci, Carrie, & McDevitt, 1997; Melnyk, Stewart, & Swink, 2004). The metrics need to be aligned with internal organizational processes and external customer and supplier performance using common definitions, data sources, and calculations, while balancing the tension between conflicting organizational priorities (Melnyk et al., 2005). Many organizations that seek to improve

their performance measurement system have initially evolved to function-specific and isolated, or stovepipe, metrics, but now want to implement a more integrated metrics system.

For instance, Figure 1a (upper left corner) displays the existing metrics paradigm when the eSCALE project was initiated in 2008. The metrics, for the most part, existed in a stovepipe environment, and their definition, source data, and interpretation varied within different AMC subordinate commands. Metrics were collected and reported, and did not reflect the performance of the entire supply chain. Moreover, the use of averages often hid issues that affect performance (Oliver, Delbridge, & Lowe, 1996)

This presented an opportunity to develop a standardized method of pulling and analyzing data across the command from multiple data systems to provide a true enterprise-wide view of the AMC's supply chain, even when the existing data systems were unable to communicate across information systems.

The new approach presented in the eSCALE project, as illustrated in Figure 1b, 1c, and 1d, involves moving away from averaging performance across the subordinate commands to measuring and monitoring exceptions in each area of the supply chain. This approach, combined with a near-real-time data engine, provides the ability to identify and address issues at the tactical level that, for example, would show overstock or understock levels by location, or production lead times beyond acceptable targets. Additionally, it provides the capability to drill down to the individual item level to identify and implement operational performance improvements. This approach identified issues with particular National Item Identification Numbers (NIIN) that could be readily targeted for performance improvement, such as the percentage of NIINs with administrative lead time (ALT) or production lead time (PLT) that were beyond acceptable standards, or stocking locations with inventory levels above requirements.

One of the key contributions beyond the SCOR approach was the selection of Customer Wait Time (CWT) for the warfighter (Retail CWT) as a focal metric for on-time performance. This is a departure from more traditional supply chain performance metrics, such as parts availability or inventory turns, and is similar to a supply-chain-spanning version of order-to-delivery (ODT) time, where we also apply CWT at each upstream echelon across four or more echelons in the supply chain (Keebler, Manrodt, Durtsche, & Ledyard, 1999). Retail CWT serves as an objective surrogate for readiness by assessing on-time performance of supply delivery to warfighters regardless

of their location in the world. CWT for upstream echelons includes real-time indicators, before delivery of the end item to the warfighter, on whether prior processes are performing on time.

To support the strategic-level metric of CWT for each echelon of the supply chain, a suite of metrics was developed for pipeline, supply, and demand management with tools for detailed analyses (Figure 1b). This approach provided leading indicators of potential issues that would, if not addressed, extend Retail CWT for the warfighter beyond targeted performance. These metrics include measures of key processes *earlier* in the upstream supply chain that would give supply chain managers early warning signals that they need to take some action *before* they fail to deliver on time to the warfighter. For instance, supplier delivery performance measures are developed to serve as leading indicators of Supplier CWT to the wholesale supply chain that eventually affects Retail CWT for the warfighter. In other words, performance measurement of upstream echelons such as suppliers and wholesale distribution helps predict expected Retail CWT for a future time. When the leading indicator falls out of the range of tolerance, it will be flagged to signal the need for some action.

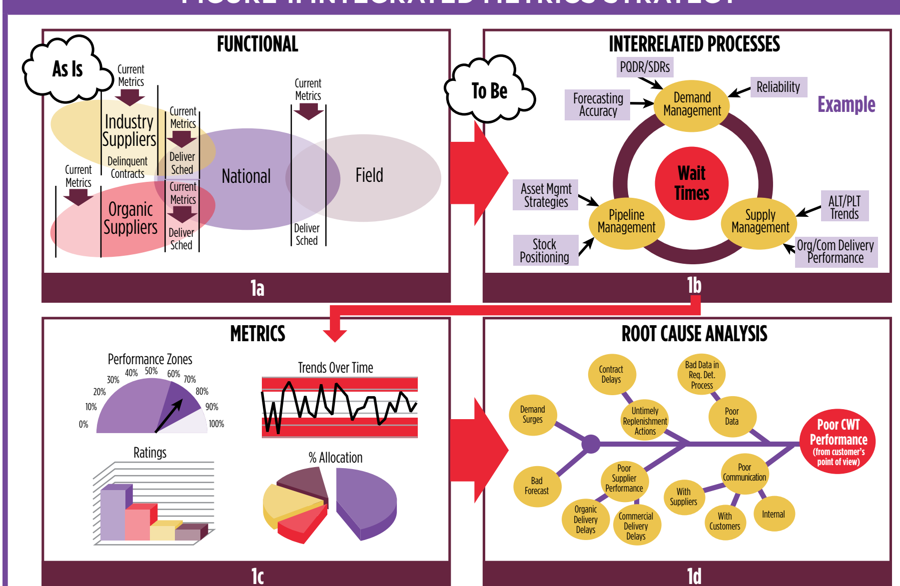
This approach improves the current process, where AMC compiles metrics that identify the number of days the soldier waits for the item, without the ability to drill down for issue investigation. The new approach also allows monitoring of drivers of CWT at each upstream echelon that could extend Retail CWT, such as demand variation, increased lead time, bad data, poor stock positioning, delivery delays, or other root causes of increased CWT (Figure 1d). Moreover, existing metrics do not allow for both a comprehensive view within a command and an aggregated view across commands along different dimensions, such as by weapon system or Army Class of Supply for parts.

Another modification of the SCOR framework dealt with the reliability metric. Reliability in the SCOR model is defined as "the predictability of the outcome of a process" (Supply Chain Council, 2016, p. 2.1.1), but does not apply to actual quality or reliability of the product or system delivered, as SCOR loosely refers to a product in "perfect condition" (Supply Chain Council, 2016, p. 2.1.1). In SCOR, reliability includes Perfect Order Fulfillment, comprising five standards that include perfect quality—which primarily focuses on perfect order documentation and the product's arrival in "good" condition. Yet in complex products and systems such as those deployed by the Army, reliable transactional processes and accurate paperwork are inadequate to ensure product reliability. In the eSCALE project,

reliability was defined by the standard adopted by DoD, which specifies that reliability is the failure-free performance of a system or product for a specified time under specified conditions (DoD, 2009; Information Technology Association of America, 2008). Reliability in this project includes initial quality and fielded reliability, using the definition above. A detailed review of the quality and reliability aspects of the eSCALE is beyond the scope of this article and is detailed elsewhere (Burns & Nicholls, 2013).

The objective of the eSCALE project was to provide visibility across the supply chain with performance measures that afford an integrated, consistent, and near-real-time view of strategic, tactical, and operational measures. With the right measures and analytical capabilities, individual supply chain managers will be empowered with the information necessary to identify and resolve issues, and make informed resource allocation decisions. Improved visibility, for example, supports improvements in inventory turns, inventory investments, and customer fill rates to soldiers. Aligning appropriate information with the existing organizational structure is expected to increase visibility across organizational boundaries. This will help improve cooperative and collaborative efforts to enhance the supply chain since increased transparency of information becomes an instrument of change rather than a source of conflict within the supply chain.

FIGURE 1. INTEGRATED METRICS STRATEGY



Integration with Acquisition

The acquisition process is integral to the new integrated supply chain performance measurement system. The new system establishes tolerances and performance norms for the suppliers, reports actual performance, and highlights exceptions to acceptable performance. As the system monitors the supplier's performance on established metrics, AMC will have the capability to create a scorecard for each organic and industrial supplier. The scorecards can aggregate performance by Life Cycle Management Command, weapon system, supplier, or from other perspectives for senior leadership review, and they provide drill-down capability to the individual item and contract level, as well as the aggregated contractor report card.

> ***It has been known for many years that integrating sourcing performance, such as via acquisition price analysis, can have a considerable effect on overall supply chain performance (Beamon, 1998).***

On-time delivery performance may suffer due to forecasting error or unexpected demand changes, which are highlighted in the metrics system. But other issues with poor CWT performance may arise. The drill-down capability of the system allows the item manager to identify issues that lead to CWT violations. Where late deliveries are not caused by forecasting error or unexpected demand changes, the metric system highlights in near-real-time other causal issues so they can either be corrected by the supplier or contract modifications can be implemented before the poor CWT performance reaches the warfighter.

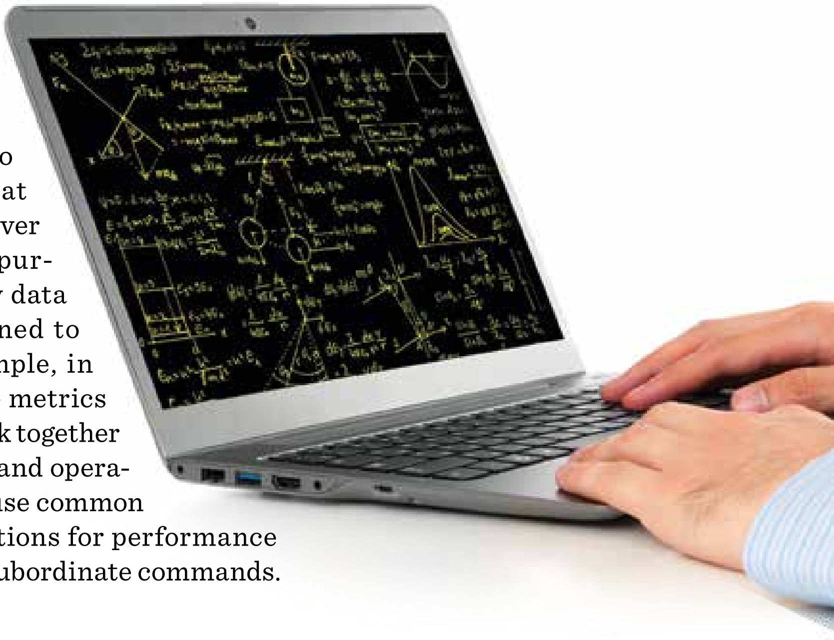
It has been known for many years that integrating sourcing performance, such as via acquisition price analysis, can have a considerable effect on overall supply chain performance (Beamon, 1998). Excessive CWT can reduce readiness and increase costs by causing a need for higher safety stock inventory. Quality and fielded reliability issues also increase cost by requiring more items to be provided to achieve an operational tempo, while also increasing maintenance and transportation costs. Each of these cost effects can be included in performance and pricing analysis at acquisition, and for some suppliers both may be present at the same time. For acquisition evaluation, the eSCALE Dashboard complements, but does not incorporate,

lagging performance data from the Contractor Performance Assessment Reporting System (2016), Past Performance Information Retrieval System (2016), or Governmental-Industry Data Exchange Program (2016).

Suppliers whose performance consistently exceeds CWT specifications can be evaluated based on actual delivered costs that are higher than quoted costs (Burns & Nicholls, 2013), providing an accurate comparison of supplier performance. For specific supplier performance, integrating these costs across AMC commands rather than by separate contracts with the supplier can show aggregated performance over time. However, for full implementation, data challenges must be addressed in the process.

Data Challenges

There are many Army data systems that handle the complex transactions and processes necessary to support our warfighters. Yet the many Army supply chain data systems are not linked into a single integrated system with highly functional connectivity to the other systems, making comparisons of performance and identification of improvements difficult (Siegl, 2008). The implementation of the Army Logistics Modernization Program (LMP), an enterprise resource planning system, for example, has created a more integrated planning system but has not facilitated an integrated, near-real-time, performance measurement system for the Army-wide supply chain. One of the reasons is that multiple data systems are required for an integrated near-real-time system to be effective, and similarly to commercial systems that have been implemented over time to serve different purposes, many of the Army data systems were not designed to work together. For example, in an integrated system the metrics should be designed to work together at the strategic, tactical, and operational levels, and should use common terminology and calculations for performance measurement across all subordinate commands.



In the development of the eSCALE performance metric system, the research team integrated data inputs from more than 10 different, nonintegrated data sources into a single performance metric architecture. The data sources, records, and fields used for each of the calculations were developed by the research team and approved by the Army sponsor with concurrence from Army subject matter experts (SMEs). This avoided incomplete data sets from one source, while providing a single Army-authorized data source for each of the calculations.

Delivered Results

By the end of the project, the architecture and framework for a full, on-time, performance metrics suite had been developed and delivered, along with a corresponding integrated framework for an efficiency metrics suite. The architecture for the quality and reliability framework had also been developed, but had not been prototyped and integrated with the on-time performance and efficiency metrics due to funding reduction as a result of sequestration. More discussion on these results and the subsequent development of the quality and reliability metrics appears later in this article.

Literature Review

The scale and complexity of Army supply chains necessitate a large and complex organization to oversee them. Over decades, organizational units with responsibility for various activities have been created, merged, and in some cases dissolved, leading to a supply chain governed by historical evolution and layers of regulation, policy, and directives. Each subordinate command specializes in supply chain management activities specific to particular weapon systems, so not surprisingly, many of the individual organizational units focus very specifically on their own domain of responsibility.

As a result of the need for specialization, over many years this separation of command responsibilities has resulted in a set of practices that can be viewed as "silos of excellence." One might wonder: would a consolidated distribution agency such as Defense Logistics Agency (DLA) solve the silo challenge? Not likely, as the solution is not that simple. While DLA has responsibility for sourcing and distributing many national stock numbers that flow through AMC, it also interacts with many suppliers, technical engineering activities, and customer groups. Also, many of the issues arise from complex and long-lead-time systems such as engines and transmissions, which require significant technical support over time. From this, our conclusion would be that the metrics framework may be of considerable use to agencies such as DLA. The multi-echelon integration across diverse data platforms is one of the strengths of the metrics framework and visual dashboard. Further benefits of this will be explained in detail in the Methodology section.

Due to the silos of functional focus that have evolved over many years, it is often difficult for management to obtain a consistent view or a comprehensive assessment of overall supply chain performance due to variation in data sources, definitions, and/or interpretation. There are many performance measurement models in use, some widely used and others that are organization-specific (Bititci, Carrie, & Turner, 2008). One widely adopted model is the SCOR model. The SCOR model helps organizations to focus performance measurement on five key processes across supply chains: plan, source, make, deliver, and return (Siegl, 2008). Another popular model is the balanced scorecard developed by Kaplan and Norton (Kaplan & Norton, 1992), which links performance measures from the financial, customer, internal business process, and innovation and learning perspectives.

Integrating and updating key business processes, avoiding inefficiencies and resource conflict across the supply chain, can be even more challenging when diverse organizations develop their own unique objectives and corresponding metrics (Henderson, 1994). This required a strategic rethinking of the entire approach to AMC enterprise-wide performance metrics as an integrated system. One way to view this approach was explained by Francis (2001), who argued for increasing operational agility to improve performance, using the example of lessons learned from military agility in the field. While extended lead times and other physical supply chain constraints make it challenging to achieve agility with all Class IX parts, lessons can be applied for those items that specifically require higher degrees of agility.

The development of an integrated suite of supply chain metrics should include strategic measures of on-time performance, quality performance, and cost performance. A metrics suite should also include drill-down subordinate metrics to support tactical- and operational-level decisions (Gunasekaran, Patel, & Ronald, 2004). This integrated cross-organizational approach supports the Joint Supply Chain Architecture (JSCA) initiative (Fletcher, 2011), which has adopted the CWT metric to measure speed of delivery to warfighters (DoD, 2012, Chapter 15.4).

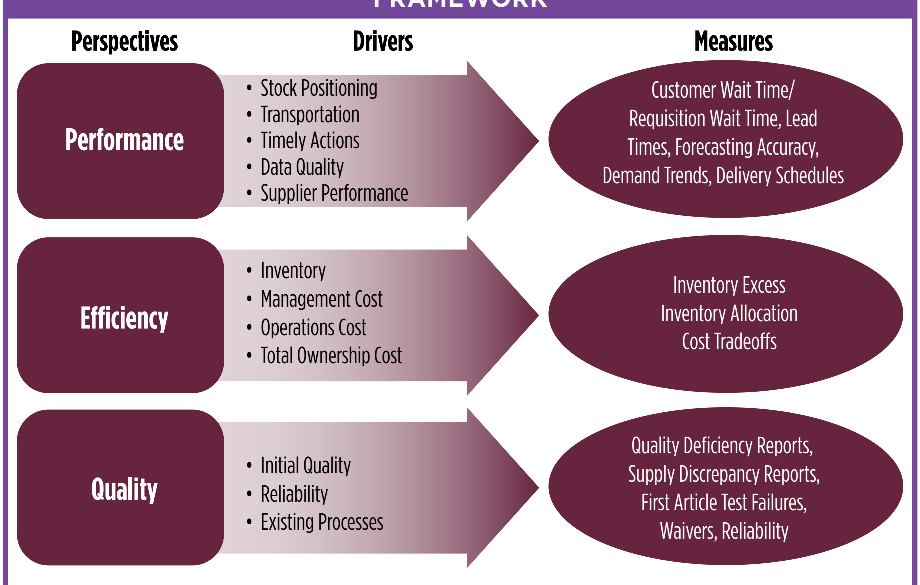
Methodology

The methodology for proposing a solution was selected from a variety of options. The first step for the Army was to choose a partner with significant supply chain expertise and knowledge of Army's supply chains, but also one that has the ability to bring diverse, unbiased perspectives and solutions to existing requirements. A UAH team of academic faculty, research scientists, and graduate students from fields such as operations research, operations management, supply chain management, marketing, economics, information systems, systems engineering, reliability, and modeling and simulation was selected to support the project. To shorten the learning curve, AMC scheduled joint-learning seminars with the UAH research team and AMC supply chain managers, supply chain specialists, and representatives from subordinate commands and organizations, such as Integrated Material Management Center, Security Assistance Management Directorate, Logistics Support Activity, Rock Island Arsenal, Corpus Christi Army Depot, and AMC G6 and G4 to discuss the overall approach and unique aspects of the Army's supply chain. SCOR principles were quickly determined to be a key element in view of DoD's adoption of the framework. It was specified that the solution would need to utilize existing data sources

rather than create requirements for new data sources. This task was complicated by the necessity to accommodate AMC's recent transition to a new SAP-based information system known as LMP (Logistics Modernization Program), which at the beginning of this multiyear project was a new deployment at Aviation and Missile Command (AMCOM). To aid in this task, potential solutions were discussed and analyzed during frequent brainstorming sessions between UAH and government representatives.

The UAH team understood the significant differences in the Army supply chains, which are geared towards rapid deployment, sustainment, and drawdown for wartime activities. This is different from commercial organizations, which tend to focus on market-based metrics such as profits, return on investment (ROI), and stock prices, and often experience considerably smaller variations over time in the scale of operations. To bridge this difference, UAH and AMC officials conducted phone interviews and site visits with several multinational commercial organizations known to apply best practice supply chain strategies. The initial seminars, meetings, and site visits resulted in an agreed-upon solution framework, which is represented in Figure 2. This article focuses primarily on CWT as an example and primary metric for on-time performance, but all of the metrics in Figure 2—and more—were included in the eSCALE performance metrics system. Space limitations prohibit a full review of all of the elements of the metrics project, which when documented filled a book.

FIGURE 2. PERSPECTIVES OF THE eSCALE MEASUREMENT FRAMEWORK



Solution Perspective and Framework

A major objective in developing the end-to-end metrics suite was to adopt a comprehensive and multidimensional approach to measure and evaluate overall supply chain performance along the dimensions of *on-time performance, efficiency, and quality*. *On-time performance* of the supply chain is driven by the chain's ability to deliver to the end customer on a time standard, specifically focusing on *speed*. Based on this notion, the approach in developing on-time performance metrics places CWT as a key metric, with the rest of the suite consisting of metrics that are likely to affect the key metric of CWT. Accordingly, the on-time performance metrics suite provides a framework for insightful analysis of how on-time performance is impacted by key drivers such as stock positioning, transportation, timely action by administrators and suppliers, data quality, and supplier delivery performance. In other words, CWT can be affected by factors such as where the stock is positioned in the supply chain, the speed with which the item was shipped to other members of the supply chain, and the timeliness of the procurement decisions made by the item manager. To assess the impact of on-time performance drivers, we measure and report metrics such as requisition wait time (RWT), demand variation, stock position, and delivery schedules, as detailed in the next section.

The Army's increased attention to inventory levels has elevated the importance of the *efficiency* metric. A recent Government Accountability Office study (Solis, 2009) reported an annual average of about $16.3 billion in secondary inventory, of which $3.6 billion (22%) exceeded current requirements. The study also revealed that, while the Army experienced excess secondary inventory, the Army had annual inventory deficits based on requirements of about $3.5 billion per year. The lack of alignment of existing inventory and current requirements was attributed to a lack of cost-efficiency metrics and goals, and inaccurate demand forecasting.

Our research revealed that inventory management, management costs, operations costs, and total ownership costs (General Accounting Office, 2003) are the primary drivers of efficiency in the Army supply chain. Metrics such as inventory excess, inventory allocation, and cost tradeoffs (e.g., repair and procurement) were developed and measured to assess the status of the drivers of supply chain efficiency.

Metrics for measuring *quality* seek to determine whether assets are functioning and performing in the field as designed and manufactured. The key drivers are initial quality, reliability, and performance of existing processes. Initially, the analysis focuses on supply deficiency reports and quality

deficiency reports. Additionally, first article test failures and waivers can serve as metrics to assess the key drivers. It was necessary in eSCALE, and in a follow-on research project, to develop algorithms to measure total costs for fielded reliability of secondary components based on planned versus actual life, which is important to containing life-cycle costs (Burns & Nicholls, 2013).

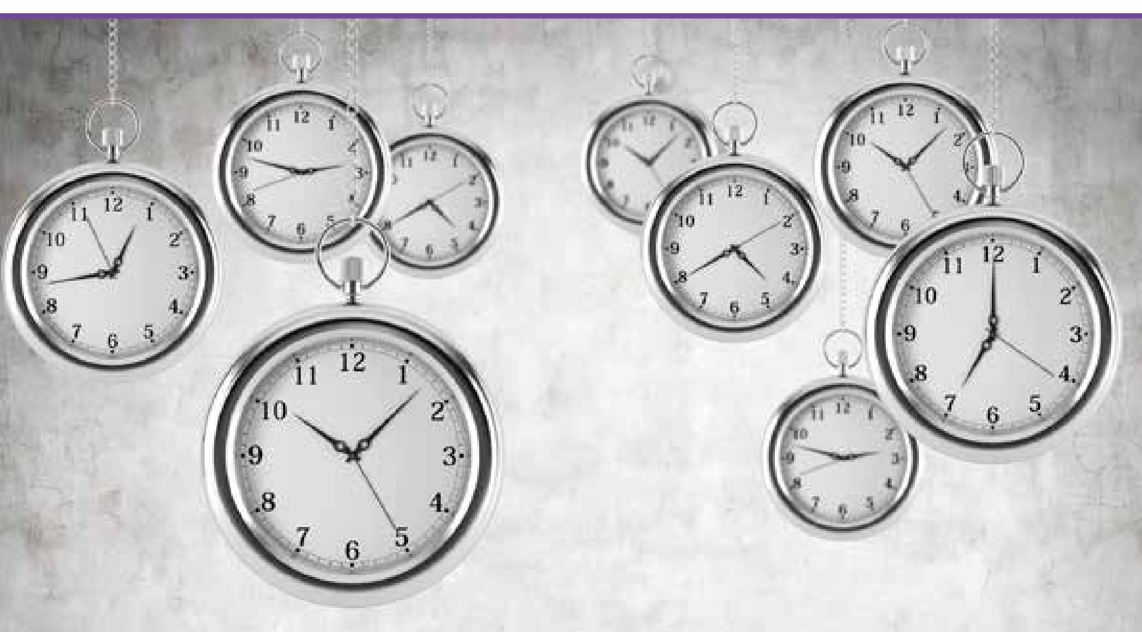
Once the initial key metrics have been formulated, the focus shifts to designing a performance measurement system that will transition away from averaging across the entire inventory to defining acceptable levels of performance and subsequently counting the number of "bad situations" (i.e., flagged issues) for each individual part that does not meet the defined standards for on-time performance, efficiency, or quality. This strategy is common across highly successful commercial organizations.

The advantage of this approach is that each individual transaction, such as a part requisition, is evaluated against the standard prior to aggregating the counts to a metric. The counts can be aggregated from multiple perspectives, such as by supply support activities (SSA), weapon system, region, priority,

and supplier, as well as by key locations in the supply chain, to show where the greatest concentration of supply chain improvement opportunities exists. The next section will detail the specific approaches used to develop the on-time performance component of the project.

The architecture of the metrics framework was designed for multiple stakeholders. For item managers, the framework identifies performance metrics and issues that will help them manage and execute their tasks for NIINs for which they are responsible. This is provided in the drill-down capability to the item level. For senior leadership and for mid-level managers, the roll-up capability aggregates and summarizes performance by responsible branches, divisions and commands, as well as by weapon system, organic or industrial supplier, and other categories of review. For issues that merit additional attention, the drill-down capability can identify areas of strong performance and areas needing additional attention at multiple levels of scrutiny, at the leader or manager's discretion.

During the development and prototyping of the metrics, we had extensive involvement with item managers and mid-level users, ongoing periodic reviews with senior leadership to obtain feedback, and confirmation of definitions and calculations for metrics and for the design of a dashboard metrics system for their use. An example of this process is detailed in the next section.



One challenge that we addressed in the Dashboard design is the issue of trade-offs of on-time performance, efficiency, and quality. A well-designed metrics system identifies and highlights such issues for decision makers. One advantage in the Army is that the hierarchical command structure naturally allows for issues regarding performance trade-offs to be identified to leadership, where well-informed leaders can make decisions on the trade-offs that cannot be encoded into any particular metrics system. We saw our role as one of helping to inform users, managers, and senior leadership of areas of high and of acceptable performance, while also highlighting areas where additional attention can lead to increased performance.

On-Time Performance

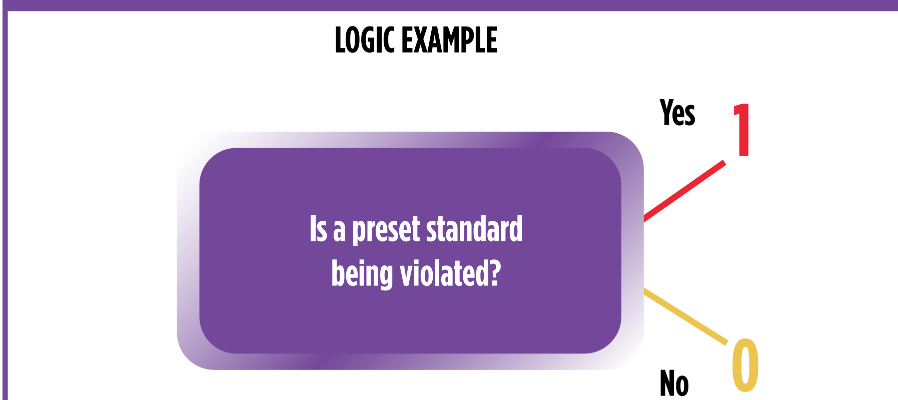
Recall that the objective of this research was to develop a supply chain system that maximizes overall performance of the supply chain and the related acquisition processes. This study proposed that on-time performance, efficiency, and quality are key metrics for assessing the overall performance of the Army supply chain. The focus of this section is on-time performance, which is driven by the ability of the supply chain to deliver to the end customer on a time standard. This details the major steps adopted in the development process of the eSCALE system that measure, report, and analyze on-time performance of the supply chain. They include the following:

- Task—Create a new effective way to measure enterprise supply chain performance.
- Concept—Unmask and trace issues, and predict trends.
- Development of Logic—Define tolerances to create standardized metrics.
- Data—Identify data sources, and acquire and verify data.
- Proof of Concept—Test logic against the inventory to get actual counts.
- Visualization—Create a visualization tool (Dashboard) to display results.
- Validation and Documentation—Assure data and process consistency and reliability across commands, and prepare for implementation.

Task. The existing metrics program's "stovepipe" environment, variations in definitions and data availability, and dependence on the use of averages preclude an accurate assessment of the performance of the enterprise-wide supply chain. Hence, the task for this project was to improve the existing system by offering the Army an integrated approach to measuring enterprise supply chain performance.

Concept. Given the prominence of readiness as the definitive measure of supply chain effectiveness, our concept for addressing the on-time performance metric focused on CWT as a viable surrogate for readiness. More specifically, we count actions, rather than report averages, which potentially mask performance issues. The goal is to know what percentage of the NIINs do not meet established performance standards. Reporting that percentage is more informative since the total number can be misleading, given the variation in size of organizations. Of course we must count both total NIINs and NIINs with issues to determine the performance. Figure 3 describes the counting logic process. The data for NIINs is evaluated against Office of the Secretary of Defense (OSD) standards. For each NIIN, if the preset standard is being violated, a 1 (yes) is assigned and an issue count is generated. Alternatively, a 0 (no) is assigned if the performance is within the standard. These results (0 and 1) are rolled up at higher levels to reflect tolerance bands and trends, as will be shown later in the discussion of the Dashboard.

FIGURE 3. COUNTING METHODOLOGY: LOGIC EXAMPLE



The count standard assesses raw data against an acceptable standard. When the data are outside the standard, a bad 'count' is generated. These are rolled up at higher levels to reflect tolerance bands and trends.

Development of Logic. The next step in the process is the development of the logic underlying the system. This step defines the tolerances to create standardized metrics across the commands. Standards were established for CWT and measures of major factors affecting CWT, including ALT and PLT, data discrepancies, demand quantity variation, delivery performance for new buys, maintenance and operations (M&O) delivery performance for both commercial and organic/depot suppliers, stock positioning, and RWT.

Supply chain managers make decisions about item deliveries based on the contract delivery schedule (e.g., deliver items within 60 days of contract signing). Yet, issues occur when the LMP data do not accurately portray the correct contract signing date. This issue is captured in the metric of ALT, which is the time between the date the item manager requests the item and the date the contract with the delivery schedule is signed. The tolerance metric for ALT states

- *If the deviation of average ALT is greater than 25% from the LMP ALT in the last 12 months, logic denotes a 1, signaling an issue.*

The numbers included in the logic above (25% and 12 months) and thereafter are proposed as examples and should be determined by proper decision-making processes for the respective NIINs.

Demand variation attempts to capture the extent to which the current demand is either the highest or lowest value compared to the previous 12 months. Tolerances might include metrics such as

- *If (the current) demand is greater than monthly demand for each of the recent X months, the logic denotes a 1, signaling an issue (a change in demand).*
- *If (the current) demand is less than monthly demand for each of the recent X months, the logic denotes a 1, signaling an issue.*
- *If demand is trending upward or downward for Y consecutive months, the logic denotes a 1, signaling an issue.*

Late deliveries are captured in the delivery tolerances for new buys, for both commercial and organic M&O deliveries. Examples of tolerance statements include

- *If the percentage of late deliveries for the current month is greater than 10%, logic denotes a 1, signaling an issue.*
- *If the percentage of cumulative late deliveries is greater than 10%, logic denotes a 1, signaling an issue.*

Using the flags by NIIN (where a signal = 1), item managers can quickly identify exceptions requiring attention. Inventory issues are related to how item managers administer their contract and procurement plans. The item manager's contract and procurement plan reflects how the item manager plans to fulfill the requirement for a particular item or component beyond the scheduled due-ins. The due-ins plus the items programmed in the contract and procurement plan should equal the forecasted requirements. The eSCALE system identifies data gaps between the demand forecast and the total supply expected from the due-in and the contract and procurement plan. The tolerance statement is

- *If the difference between the total of all due-ins, contract and procurement plans, and the forecasted requirements is more than Z units in month 1 of the planning horizon, the logic denotes a 1, signaling an issue.*

Since serviceable items should always be located as close as possible to the customer and repairable items should be located at the appropriate repair facility, a major goal for the new system is to identify where inventory might be better positioned in the pipeline. For instance, a serviceable depot-level repairable item located in an organic repair facility rather than the SSA where it could be issued to the customer would be considered an issue. Moreover, an unserviceable item that can be repaired only by the contractor should be located at the contractor repair facility rather than the organic repair facility, the SSA, or an area operated depot (AOD). Figure 4 demonstrates how the eSCALE system identifies stock locations. A flag of 1 represents inventory that can be better positioned.

FIGURE 4. PERFORMANCE PERSPECTIVE: LOGIC STATEMENTS

Stock Positioning: Part Type
Identifying where inventory position can be improved in the pipeline

	Contractor Repair Facility	Organic Repair Facility	SSA	AOD/CCP
DLR Serviceable	1	1	0	0
DLR Unserviceable	0	0	1	1
FLR Unserviceable	1	0	1	1
Contractor Repair Only Unserviceable	0	1	1	1
Contractor Repair Only Serviceable	1	1	0	0

Note. DLR = Depot Level Reparable; FLR = Field Level Reparable.

A more unusual stock-positioning challenge relates to stock positioning at the SSA. One challenge occurs when there is unforeseen demand for an item not on the Authorized Stock List (ASL). The second challenge occurs when items continue to exist on the ASL (Requisition Objective > 0) when there is no current demand for the item. The tolerance statements for these two conditions follow:

- *If the Requirement Objective (RO) = 0 and demand is greater than 3 in the past year, logic denotes a 1, signaling an issue.*

- *If the Requirement Objective (RO) is greater than 0, and demand = 0 in the past year, logic denotes a 1, signaling an issue.*

The amount of time that the SSA waits to receive the requisitioned item from the wholesale organization, such as AMCOM, is RWT. RWT is also an important factor in determining the amount of time the final customer must wait for an item or component, CWT. Hence the following tolerance was established:

- *If the requisition wait time is longer than TRANSCOM [Transportation Command] regulation for CONUS/OCONUS [Continental U.S./Outside Continental U.S.], the logic denotes a 1, signaling an issue.*

CWT is the seminal variable in the eSCALE system, since it is our surrogate for readiness. The variables used in the model discussed above (e.g., demand variation, stock positioning) were selected because of their potential negative impact on CWT. The customer is the warfighter, who secures the product/item/component from the SSA. The ordering process begins when the soldier completes the appropriate order paperwork. The resulting requisition records the date and time the requisition was filed at the SSA. The process is completed when the soldier receives the item from the SSA. The time between the date and time of the requisition submission and the date and time the soldier received the item is the CWT. While most stock items are available for immediate distribution to the customer, the eSCALE system identifies instances when the CWT exceeds the established tolerances.

- *If the Requisition Objective (RO) is greater than 0 and more than 15% of the requisitions for an item took longer than 3 days, logic denotes a 1, signaling an issue.*
- *If the Requisition Objective (RO) = 0 and more than 15% of the requisitions for an item took longer than TRANSCOM standards, logic denotes a 1, signaling an issue.*

The metrics discussed above were developed out of many meetings and discussions with different Army agencies across the supply chain. For metrics to be useful, they must be supported by data that are accessible, accurate, consistent, and current.

Data and Proof of Concept. The development of metrics and the logic for metrics calculations and flags for performance improvements cannot be separated from the process and effort of identifying data sources, and acquiring and verifying data. The research team collaborated closely with Army SMEs in this effort, with approvals by senior leadership.

Since the Army supply chain consists of organizations that are specialized in their functional areas, it soon became evident that identifying data sources for the metrics was the first essential step. Working groups were formed, with representatives who are mostly SMEs from organizations managing or supporting the supply chain, to reach agreement on metrics and standards for the supply chain Dashboard and to identify data that will be used to calculate metrics and data sources. Once the data sources for metrics were identified, more time-consuming tasks followed our acquisition of sample data for analysis and testing of proposed metrics to prove the concept.

Proof of concept involved testing the logic against the available data and evaluating the logic with Army SMEs. The tasks were not in sequential order—it took a lot of back and forth among the UAH team and Army commands. Iterative steps ensued during this collaborative process, from defining metrics to identifying data sources, acquiring data, verifying

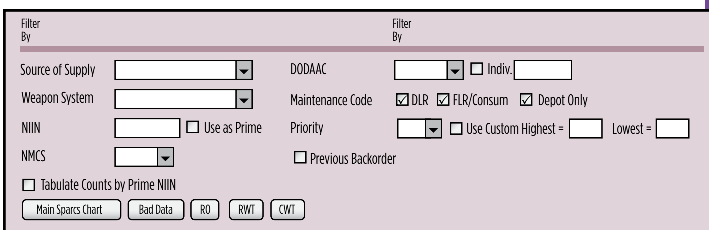
data, testing metrics with acquired sample data, and testing metrics with full-scale data. It was essential to do this in order to obtain a consistent, enterprise-wide view and a comprehensive performance assessment of the supply chain.

Visualization. A new visualization tool, the Dashboard, was developed to facilitate a departure from reporting averages across the entire inventory and focus on counting of "flagged" areas in the individual supply chain elements with the ability to drill down to the individual item level. Figure 5 provides an example of the Dashboard, which includes the standards and logic for the CWT metric. To support the drill-down and root-cause analysis, the Dashboard presents the total number of issues by category for each month and year, and the specific number of issues by potential causes, such as demand variation and stock positioning. Possible sources of issues related to the various causes of CWT are also listed. This top-level chart summarizes all issues across the various categories. This particular chart—showing only notional data for confidentiality reasons—reports at the bottom left a total of 25,070 NIINs for the requested supplier, dates, and maintenance codes. Of the 25,070 NIINs, 5,007 have at least one issue, such as late delivery or a documentation issue. Hence, 20,063 have no (0) issues. A further reading reveals that 3,322 NIINs have one issue and 4 NIINs have five issues. You

will note, that in this particular analysis, most issues occur because of data issues ("Bad Data"), improvable stock positioning ("Stock Positioning"), and excessive time to process requisitions (RWT).

FIGURE 5. PERFORMANCE PERSPECTIVE: DASHBOARD DEVELOPMENT

Available Filter Options



The chart sums up all problems across various categories. For instance, **out of 25,070** NIINs, **4** are flagged as having problems in five categories.

Top Level

Sum of Problems	#NIIN	Bad Data	Demand Var.	New Buys	Commerce	M&O Organic	Inven. Probs.	Stock Pos.	RWT	CWT
9	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
5	4	4	3	0	0	2	0	4	4	4
4	102	91	14	0	0	10	0	101	101	91
3	519	309	26	0	0	27	0	486	475	236
2	1,059	386	27	9	9	17	0	851	673	214
1	3,322	2,201	15	0	0	28	0	643	268	169
0	20,063									
Probs	5,007	2,990	85	0	0	84	0	2,086	1,471	714
All	25,070	18,059	9,699	0	0	2,896	0	9,170	5,972	6,022

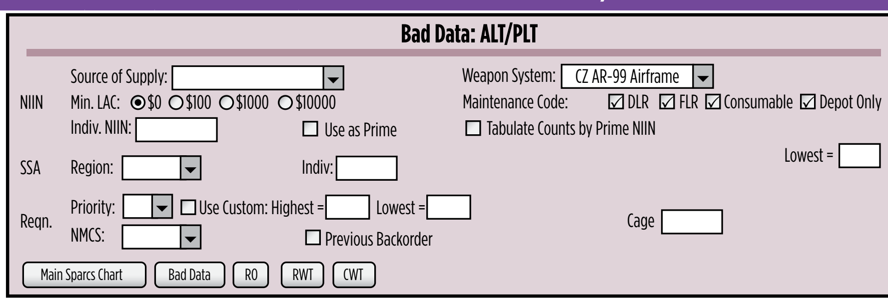
Individual columns illustrate specific metric areas. For M&O Organic, **84** NIINs had greater than 10% delivery delays out of 3,351.

Note. DODAAC = Department of Defense Activity Address Code, Sparcs = supply problem analysis, reporting and categorization system.

Figure 6 represents the Dashboard's drill-down capability, which provides a more detailed presentation of *bad data* issues related to ALT and PLT for the CZ AX-99 Airframe (actual weapon system code disguised). In this notional

example, there are 91 NIINs reported. Seventy-one have at least one bad data issue related to ALT or PLT, so only 20 NIINs have zero (0) ALT or PLT issues. Eighteen NIINs report one issue and 53 report two issues. Of the 18 NIINs with only one issue, 13 are data discrepancies related to ALT and 11 are data discrepancies related to PLT.

FIGURE 6. PERFORMANCE PERSPECTIVE: BAD DATA DRILL DOWN—ALT/PLT



Bad Data

Sum of Problems	#NIIN	ALT	PLT	
2	53	53	53	⇐ NIINs with Bad ALT and Bad PLT Values
1	18	13	11	⇐ NIINs with either Bad ALT or Bad PLT Values
0	20			
Probs	71	66	64	Click for drill down on root cause
All	91	91	91	

Note. LAC = latest acquisition cost, NMCS = not mission capable supply.

To examine additional drill-down capabilities to understand issues, using an example, the item manager simply clicks on the number "13" under ALT in Figure 6 to review details on the 13 NIINs with ALT issues. Figure 7 presents analysis of the 13 NIINs where the actual ALT dates differ from the system's data dates by more than 25%, a preset level of tolerance. This report reveals each of the 13 NIINs with both a distribution and numerical percentage deviation between the actual ALT and the ALT reported in the LMP data files. For instance, the percentage deviations between the actual ALT and the ALT from the data file are shown in the highlighted (and disguised) NIIN on the right (83609549146) to be 41%. Since 41% is greater than the acceptable tolerance of 25%, it is flagged on this screen and the item manager can investigate the issue for that particular NIIN by clicking on the

NIIN for additional drill down. The results for Figure 8 show that the NIIN is for a spherical gear for weapon system CZ. The actual ALT is 28.8 days and the LMP system ALT (days) is 20.4 days (data disguised). The manager should investigate the causes of this discrepancy.

FIGURE 7. PERFORMANCE PERSPECTIVE: BAD DATA DRILL DOWN—ALT/PLT: ALT

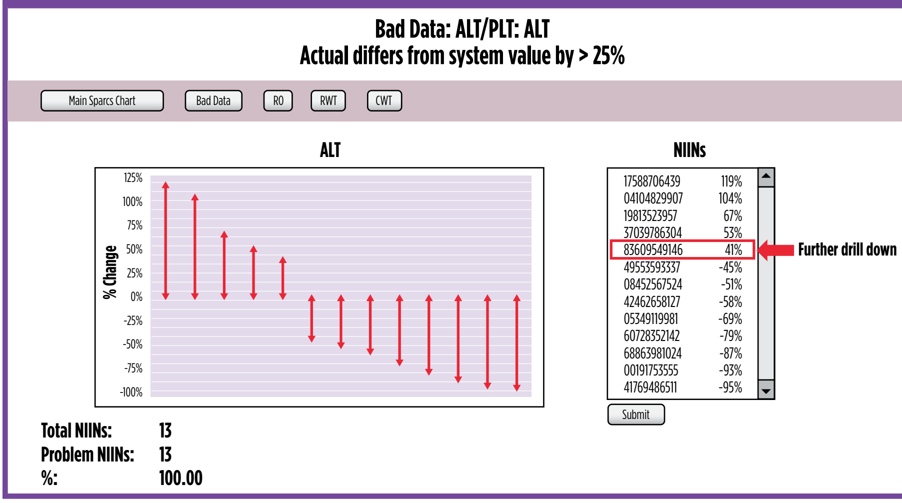


FIGURE 8. PERFORMANCE PERSPECTIVE: BAD DATA DRILL DOWN—ALT/PLT: ALT: SELECTED NIIN

Bad Data: ALT/PLT: ALT: Selected NIIN

Main Sparcs Chart | Bad Data | RO | RWT | CWT

NIIN	**83609549146**
Prime NIIN	**83609549146**
Nomen	**Gear, spherical**
Weapon System	**CZ AR-99 Airframe**
SOS	**AMCOM Aviation Command (B17)**
Actual ALT (days)	**28.8**
System ALT (days)	**20.4**
% Difference	**41.2%**

Note. Nomen = nomenclature, SOS = source of supply.

Validation and Documentation. Before the Dashboard can be implemented, steps must be taken to assure data and process consistency and reliability across commands. Data validation is a major milestone before tool

deployment. Validation means signing off on the data—each data element—being analyzed in the Dashboard, including calculations, data sources, and data analysis. Validation can also include the Dashboard layout and how the data are presented. A data validation plan should be made to determine the validation process, approach, and data teams.

Documentation provides a path to communicate our methodology and to meet Army's information assurance certification requirements. It also helps the data validation process. We documented the project with specifications, data structures, logic algorithms, and user applications and instructions to help educate item managers and other users on the capabilities and interfaces of the performance metrics system framework.

Benefits and Application

The delivered architecture for how to implement the improved metrics framework has allowed the integration of existing metrics, such as those adopted through SCOR, with improvements such as a focus on CWT that is integrated with efficiency. In addition, through continued development of the quality and reliability metrics initiated in this project and further developed in a follow-on project (Burns & Nicholls, 2013), algorithms for assessing the cost of initial quality and fielded reliability have been developed as a complementary metrics architecture for the more fully developed on-time performance and efficiency metrics in the eSCALE project.

The proposed metrics system will enable managers to shift their focus to measuring and evaluating performance, communicating performance expectations, directing attention to areas requiring management intervention, and helping to identify root causes of performance challenges for both AMC and its organic and industrial suppliers. More importantly, it will help expose critical issues and provide the basis for launching new initiatives for improving the supply chain. For instance, following the identification of challenges, opportunities, and goals, a "tiger team" of SMEs could be formed within various segments of the supply chain.

One such example was a recent eSCALE project that conducted simulation studies providing insights on how to improve supply chain efficiency while decreasing the time it takes to deliver long-lead-time items. It was observed that lead times for aviation and missile parts have been increasing, contributing to increased inventory pipeline costs. To reduce lead times and overall inventory pipeline costs, new contracting strategies were needed

for deploying strategic Work-in-Progress (WIP) inventory at different locations in the upstream supply chain. Strategically placed WIP has the potential to increase the supply chain's capability to meet demand surges and meet weapon system readiness requirements while helping to reduce overall inventory. Another example of the increased visibility was the identification of issues to improve supply chain performance in theater and other areas. Soon after the issues were identified, item managers were able to enact strategies that resulted in real supply performance improvements to our warfighters.

> ***The proposed metrics system will enable managers to shift their focus to measuring and evaluating performance, communicating performance expectations, directing attention to areas requiring management intervention, and helping to identify root causes of performance challenges for both AMC and its organic and industrial suppliers.***

The simulation examined the impact of shifting the burden of the safety stock, holding costs, and pipeline costs into the supply chain. The research showed that investing money in strategically located companies, upstream in the supply chain, and holding more than the minimum stock could lead to shortened service times with an increased capability to meet demand surges and weapon systems readiness requirements.

In the process of developing the new system, many such complexities were revealed and led to interesting research projects by the project team. A recently completed graduate thesis, for instance, investigates the inventory stock-out issue of class IX items (Neidert, 2011). Items with stock-out issues are identified and characterized by statistical analysis. The study proposed a framework and tool for inventory management based on factors such as the inventory level and trend of items. The stock position of an item is forecasted with relatively high accuracy, which would assist supply chain managers in their inventory decisions. For instance, using this framework can help to evaluate whether items are likely to be overstocked or understocked. The model has been well received, and the framework is being used as the basis for a more in-depth analysis of supply chain efficiency.

While the project team made considerable technical progress on the development of a more real-time and integrated metrics system to enhance the current system, the team did not address organizational and cultural elements that are typical in any large-scale organization. However, our observation is that in the time since the project, AMC and subordinate commands have included insights from this and other projects to make important progress on improving their metrics systems.

Conclusion

Integrating performance metrics in an end-to-end supply chain requires a conscientious effort to identify, define, and calculate performance metrics from authorized data sources to provide a broad set of lower level metrics. Integrating lower level metrics into a higher level metrics system requires that data sources from nonintegrated systems be integrated into a system that automatically pulls and accumulates detailed data into local and aggregated measures to provide cascading levels of detail that support local and leadership decision making. Data integrity and cleansing are an integral part of the process, as is reaching common agreement—in this case with the Army—on appropriate data sources, algorithms to calculate metrics, and the design of a dashboard that supports leadership decisions and performance evaluation at higher levels, with drill-down capability for lower level decision making.

Focusing on the end customer, such as warfighters, drove the development of measures such as CWT. To support the best and most capable national defense, we must make sure our warfighters receive the supply support they need at the time they need it. Making sure this process works well over time requires a performance measuring and reporting system that directly supports high performance on measures such as CWT.

The Army and UAH partnership on the eSCALE project led to learning and improvement from both partners and resulted in the development of CWT as the primary high-level metric for on-time performance, which was adopted by JSCA (Fletcher, 2011). Additional advances have been made by UAH, with Army support, on development of an integrated metrics system that includes quality and reliability, and how high CWT and lower levels of quality and reliability negatively affect life-cycle costs, as measured by total ownership cost (Peeler, 2003). Those advancements are the subject of a future article (see Burns & Nicholls, 2013).

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Biographies

Dr. Fan T. Tseng is professor of Management Science and currently the department chair of Information Systems, Management, and Marketing in the College of Business Administration at the University of Alabama in Huntsville. His current research interests include supply chain analytics and healthcare analytics. He has conducted research in operations research and operations management, and has published in areas including supply chain, healthcare, scheduling, optimization, heuristics, and simulation.

(E-mail address: fan.tseng@uah.edu)

Dr. Laird Burns is associate professor of Management Science and Supply Chain Management in the College of Business at the University of Alabama in Huntsville. He was a group hire between the colleges of business and engineering. His research interests include supply chain design and related work in systems engineering, risk and resilience in supply networks, dynamics of integrated supply networks, supply chain management, quality and reliability, life-cycle costs, agent-based modeling, operations management, and complex systems.

(E-mail address: laird.burns@uah.edu)

Dr. James T. Simpson is distinguished professor emeritus and principal research scientist in the College of Business Administration at the University of Alabama in Huntsville. His research has appeared in leading academic journals such as *Journal of Marketing Research, Journal of Business Research, Journal of Systems and Software, Decision Support Systems,* and *European Journal of Innovation Management*. He has lectured at universities in Russia, China, Romania, Ireland, France, and England.

(E-mail address: james.simpson@uah.edu)

Dr. David Berkowitz is dean of graduate studies and professor of Marketing at the University of Alabama in Huntsville. His research focuses on innovation, product development and supply chain for complex, long life-cycle products. His research has appeared in journals such as the *Journal of Retailing, Journal of Advertising Research, Journal of Advertising, European Journal of Marketing, Defense Acquisition Review Journal*, and the *Journal of Product Innovation Management*.

(E-mail address: david.berkowitz@uah.edu)